Tripropellant Injector and Combustion Technology

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205–544–2260

A tripropellant engine provides an opportunity to burn hydrocarbon fuel with oxygen efficiently during the boost phase and hydrogen with oxygen afterwards. This concept offers possible advantages for application in a reusable launch vehicle for reasons of weight and cost savings, since only one engine needs to be developed.

To advance the state of the art with respect to the development of injection elements, Pennsylvania State University has designed two types for testing. The first one, a tricoaxial swirl injector (fig. 42), uses the swirling liquid RP–1 in the center and is subsequently surrounded by cylindrical co-flowing jets of gaseous hydrogen and gaseous oxygen. The rotating RP–1 leaves the center post and forms a hollow cone at a 35-degree angle. The inner radii of the RP–1, gaseous hydrogen, and gaseous oxygen exit openings are 0.135, 0.165, and 0.345 inch, respectively.

The second type, an effervescent atomizer (fig. 43), is similar in design to a shear coaxial element. The major difference is that both fuels, RP–1 and gaseous hydrogen, share the center post. The gaseous hydrogen flow enters the liquid RP–1 through three holes located upstream of the center post-exit plane and forms the effervescent fluid. The inside diameter of the center post is 0.5 inch, whereas the inner and outer diameters of the gaseous oxygen annulus are 0.18 and 0.5 inch, respectively. During cold-flow testing with gaseous nitrogen and water simulants, liquid drop sizes were obtained from photographs, which indicate that the liquid atomization improves significantly with increasing the gas-to-liquid volumetric ratio.

An initial series of tests has been conducted with both injection elements, using a 2- by 2-inch unielement combustor. For the tripropellant operation, an overall optimum mixture ratio of oxidizer to fuel was based upon an established mixture ratio of gaseous oxygen/RP–1 of 2.4 (yielding high performance), together with the stochiometric mixture ratio for gaseous oxygen/hydrogen of 8.0 (producing the maximum temperature). Test results using various mass percentages of gaseous hydrogen were then compared with the experiments in which no hydrogen was injected at all. The results revealed that for an increase of hydrogen up to 10 percent, the combustion efficiency, η_{C^*}, rose from 82 percent to 98 percent for the tricoaxial swirl-injection element, while an increase from 83 percent to 96 percent was noticed for the effervescent element. The higher combustion efficiency may be caused by a combination of the gaseous oxygen/hydrogen combustion and improved RP–1 atomization due to momentum transfer between the gaseous hydrogen and RP–1 flows.

Penn State is currently performing parametric hot-fire tests to provide details of the combustion flow field and injector performance characteristics.

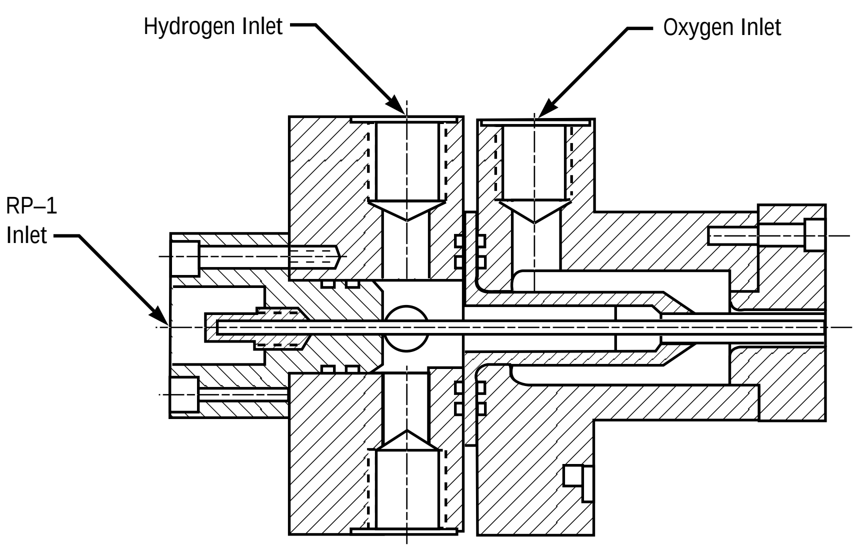

FIGURE 42.—Tricoaxial swirl injector for gaseous oxygen/RP–1/gaseous hydrogen.

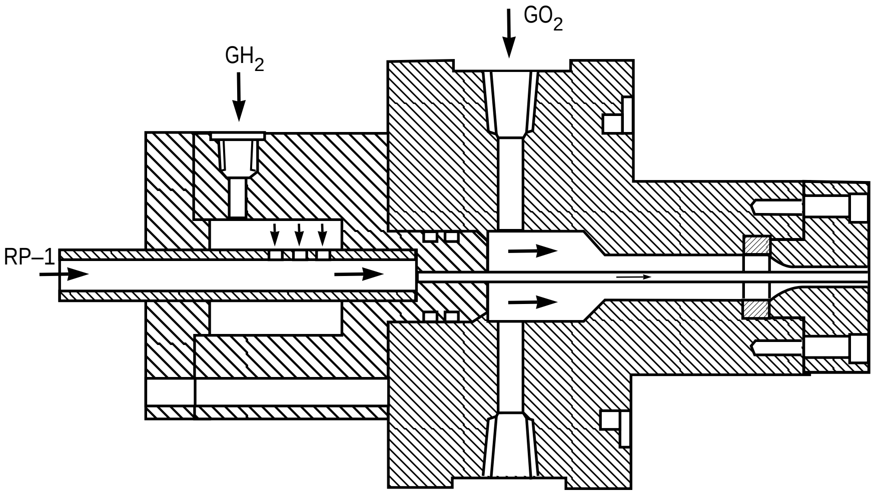

FIGURE 43.—Effervescent injector for gaseous oxygen/RP–1/gaseous hydrogen.

Sponsor: Office of Space Access and Technology

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